Priming of native soil organic matter by pyrogenic organic matter

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Introduction

What is priming in relation to pyrogenic organic matter?
Priming, in relation to pyrogenic organic matter (PyOM) investigated here, describes the change in mineralization rate of non-pyrogenic ("native") soil organic matter (nSOM) due to the addition of PyOM. Priming may be 'positive', in that the addition of PyOM increases the mineralization rate of native SOM, or 'negative', in that the mineralization rate of nSOM is decreased.

Why is it important?
Soil organic carbon (SOC) makes up a significant and active portion of the global organic carbon pool, and of this SOC, PyOM-C can account for up to 45% (Singh et al., 2013, Bird et al., 1999)! These are enormous OC pools, and so understanding how PyOM may affect or "prime" the cycling of nSOC or vice versa; this may have large implications in our knowledge of OC cycling and potential C storage. In order to study these interactions and to incorporate this process into future OC models, we must break them down to the mechanistic level. A growing body of work is taking this approach in building the knowledge surrounding PyOM priming.

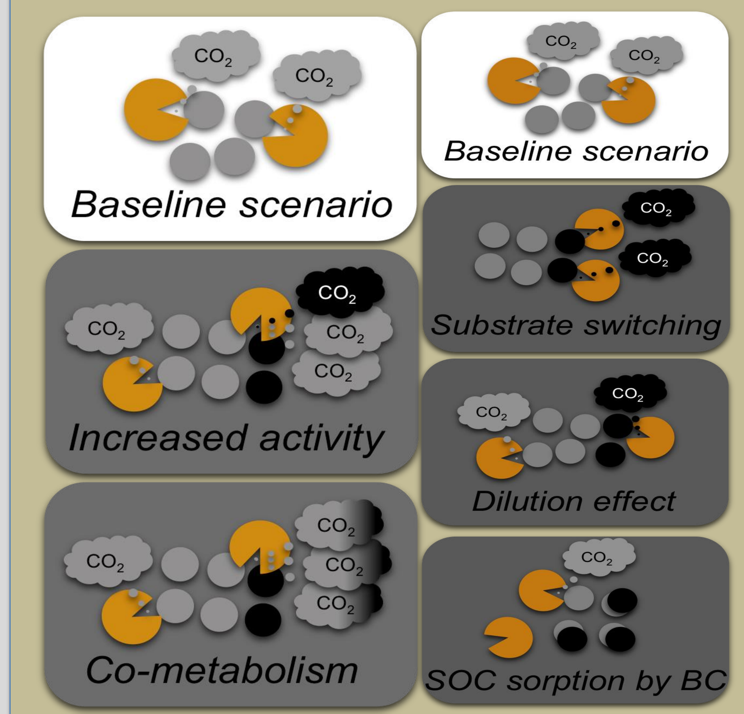


Figure 1: (left) examples of positive priming mechanisms
Figure 2: (right) examples of negative priming mechanisms; orange pac-men represent microbes, grey circles: nSOM and black circles: pyOM. Adapted from Whitman, 2014.

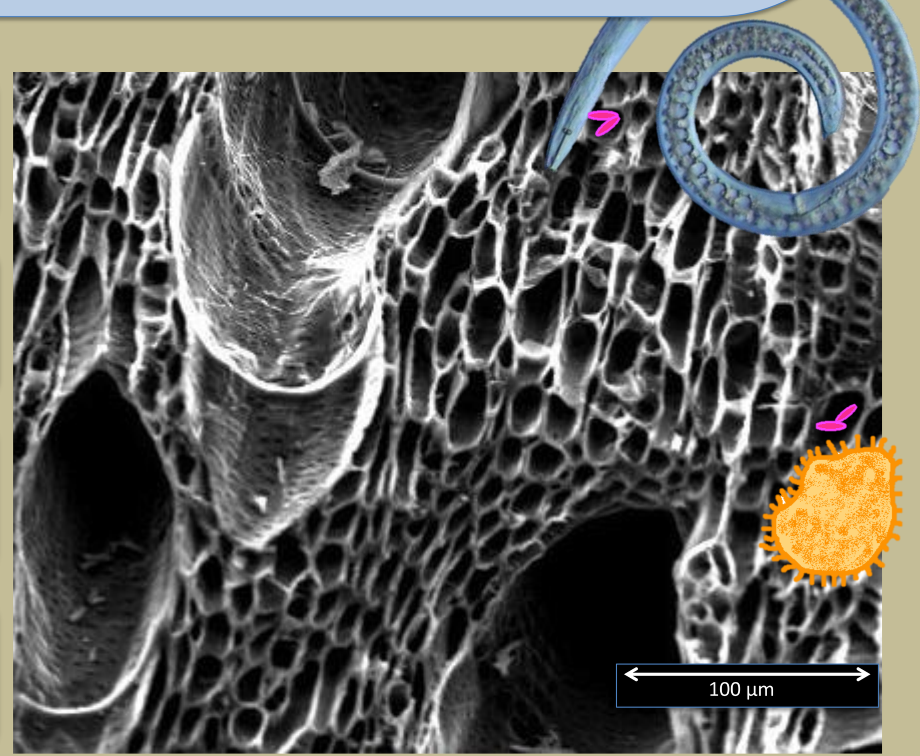


Figure 3: SEM photograph of wood-derived biochar showing the high concentration of pores on biochar surfaces. Microbes (pink) may find protection from predators (orange and blue) within pores. (Adapted from Lehmann and Joseph, 2009.) (Nematode photo by Terry Niblack, Ohio Agriculture Journal)

What are the proposed mechanisms?
Positive Priming
- Stimulation (fig. 1)
- Co-metabolism (fig. 1)
- Nutrient mining
- Microbial protection (fig. 3)
- Microbial community shift

Negative priming
- Inhibition
- Preferential substrate utilization or switching
- Sorption (fig. 2)
- Stabilization
- Substrate dilution (fig. 2)

Past Work

Effect of Repeated Residue Additions
Dharmakeerthi et al. conducted a seven year long incubation study, and found that PyOM additions increased total OM mineralization for the first 2.5 years, was equal to control after 6.2 years, and was 3% lower after 7.1 years. Cumulative nSOM mineralization was 23% less with the PyOM additions than without, and over 60% of the added PyOM was present in the labile soil fraction after the 7 year incubation. Repeated additions of crop residues over seven years did not result in higher mineralization rates of the residue and nSOM. (Figure 4)

Effect of Plants and PyOM
Whitman et al. conducted several shorter incubation studies. Using *Zea mays* in a pot trial, we found that over the course of the 80 day trial, increased nSOC mineralization due to the presence of plants (positive priming) was counteracted by PyOM additions (negative priming) (Figure 5).

Effect of mineralizability of added PyOM substrate
In another incubation trial, soil was pre-incubated for 6 months before use in the incubation jar. This study found that there was no ideal pre-incubation time for soils in these studies, but rather that the mineralizability of the carbon added as PyOM was more important in facilitating priming interactions (Figure 6).

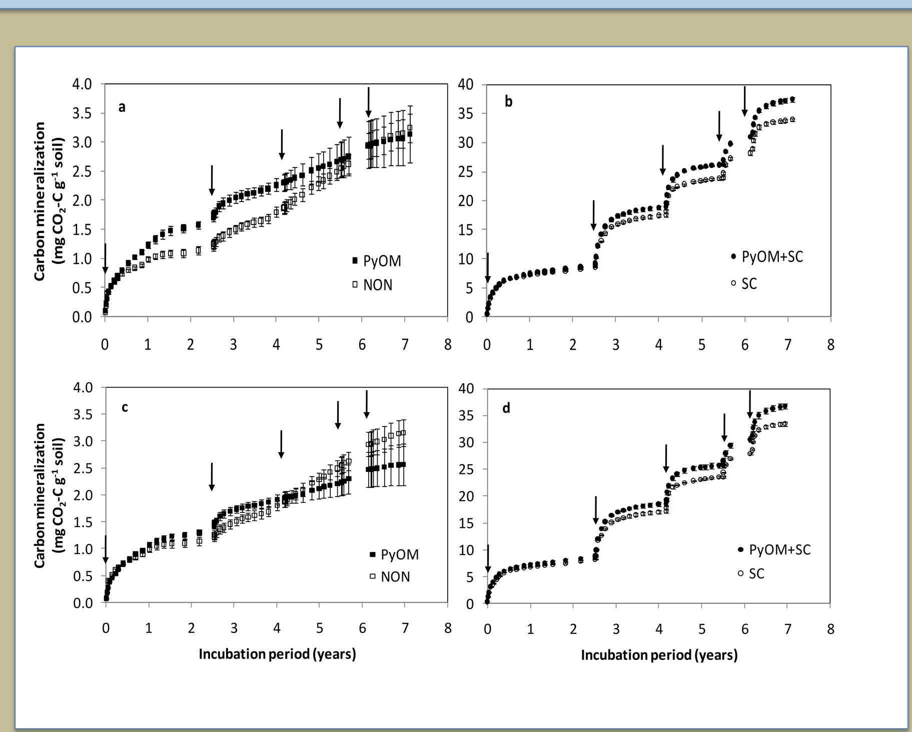


Figure 4. Cumulative CO_2 released from all OM sources with PyOM (PyOM) and without any additions (NON) (a), with sugarcane (SC) and the combination of PyOM and sugarcane (PyOM+SC) (b), from native soil organic matter (nSOM) in treatments PyOM and NON (c), and from sugarcane plus nSOM in treatments (SC and PyOM+SC) (d). Note the differences in scales of the y-axes. Arrows indicate sugarcane additions and/or mechanical disturbance of the soil (means and standard errors; n=3) (Dharmakeerthi et al. In Review)

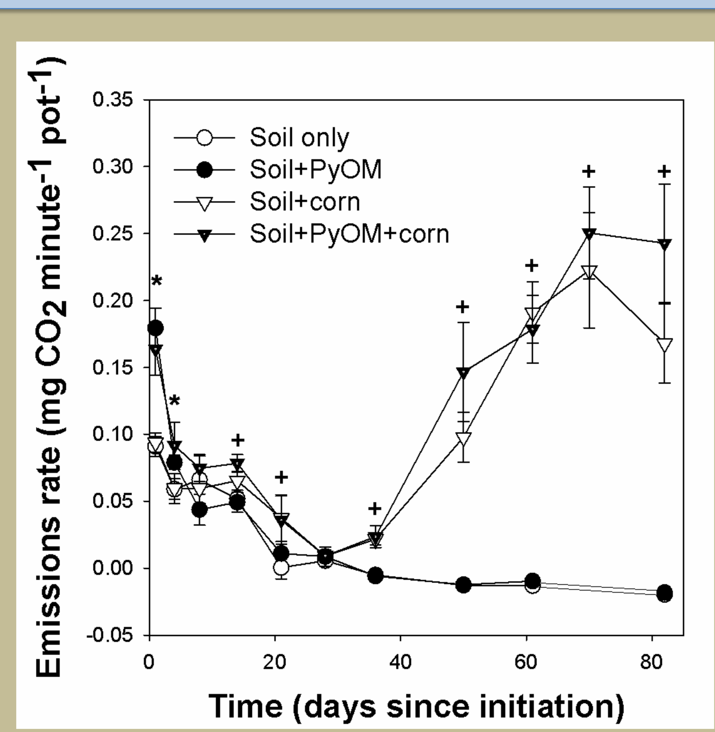


Figure 5. Emissions rate over time. Error bars are ±1SE. * indicates significant differences between the +PyOM and -PyOM pots (*t*-test, p < 0.05, n=12), and **+** indicates significant differences between the +corn and -corn pots (*t*-test, p < 0.05, n = 6). (Whitman et al., 2014)

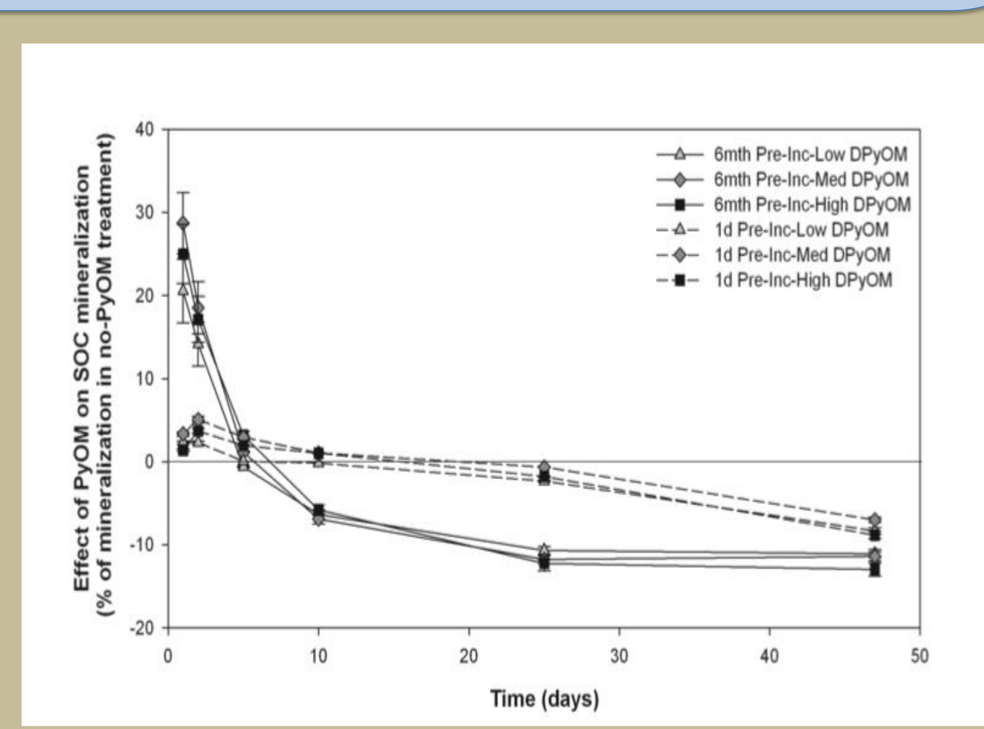


Figure 6: Mean cumulative relative effect of PyOM additions on SOC mineralization over time: (SOCPyOM-SOCno PyOM)/SOCno PyOM. Dashed lines indicate 1-day pre-incubated soils; solid lines indicate 6-month pre-incubated soils. Black squares, dark grey diamonds, and light grey (Whitman et al. 2014)

Current Work

Overall Objectives
1. To quantify the priming effects of PyOM substrates on nSOC, and determine how these effects vary under different conditions.
2. To determine which mechanisms dominate priming interactions.
3. Apply the findings of objectives 1 and 2 to current carbon cycling models.

My current questions/experiments:
1. **Q.** How does temperature of charring effect priming?
Is increased sorption capacity correlated with surface area or porosity?
P: We are using a range of PyOM produced at different temperatures and adjusted for pH and labile carbon content
3. **Q:** What effect does labile carbon have on priming?
P: We pre-treated chars with an acetone wash to remove labile carbon to use in the present incubation. We are also including a treatment that adds fresh uncharred biomass to soil, and are using soils with three distinctly different carbon contents.

Incubation jar! The Picarro can analyze 112 samples simultaneously.

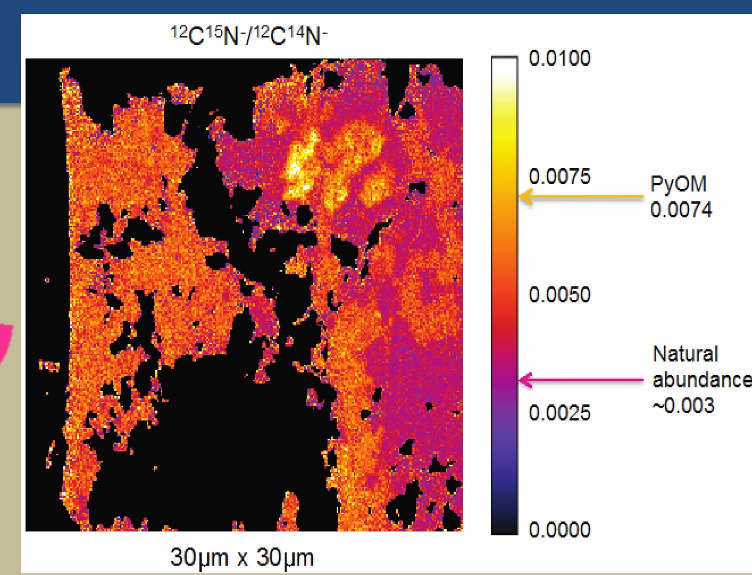


Figure 7: Calculated nano-SIMS image of 15N/14N ratio (as 12C15N- and 12C14N- ions detected on 200 scans of nanoSIMS) across a 30!m x 30!m region of selected incubated PyOM particle. Note that the 15N/14N ratio of naturally-occurring organic matter is about 0.0037, while labelled sample was 0.0074. Thus, orange (light) areas indicate PyOM, while pink (dark) areas indicate sorbed SOM. Black regions indicate non-OM regions (soil minerals) or regions with low-resolution data due to image shifting during scanning. Nano-SIMS is currently the most promising technique for observing interactions between pyOM and nSOC at the micro scale. (Whitman et al., 2014).

New Data!

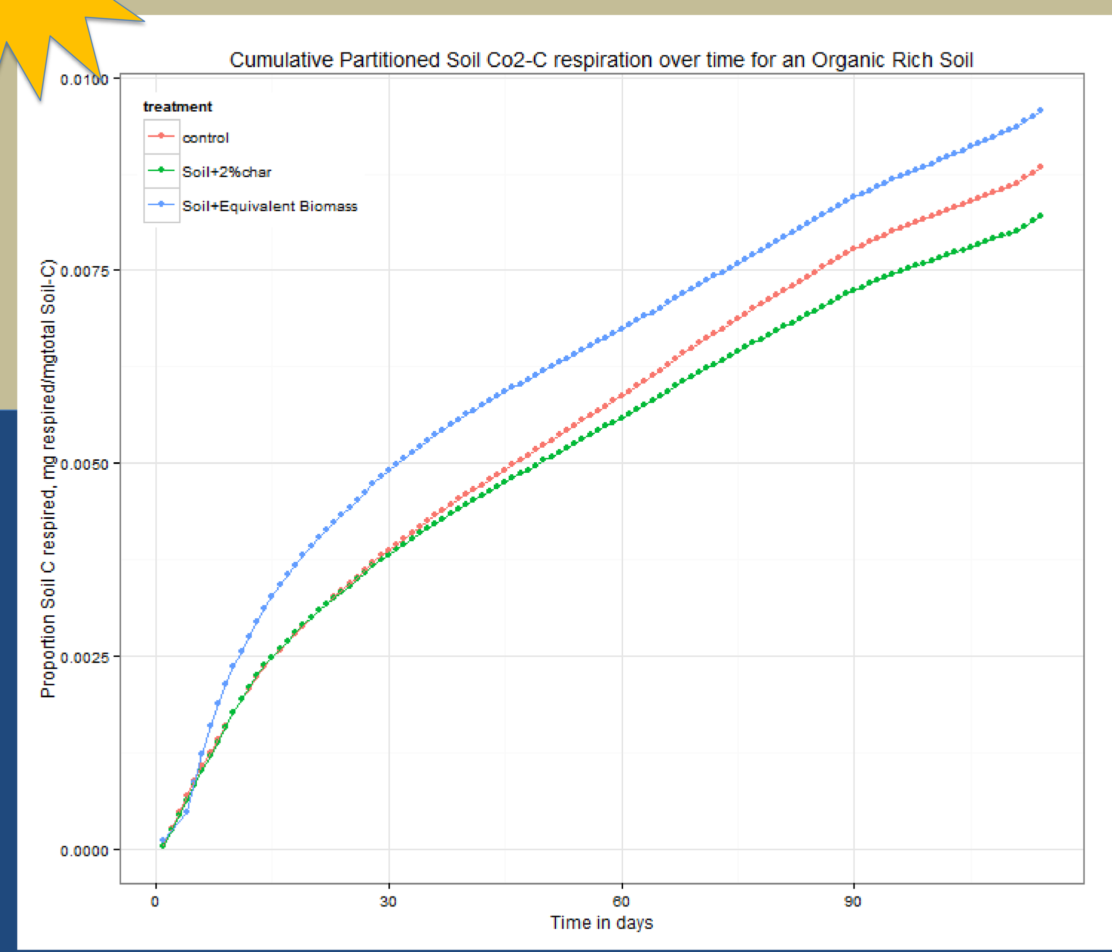
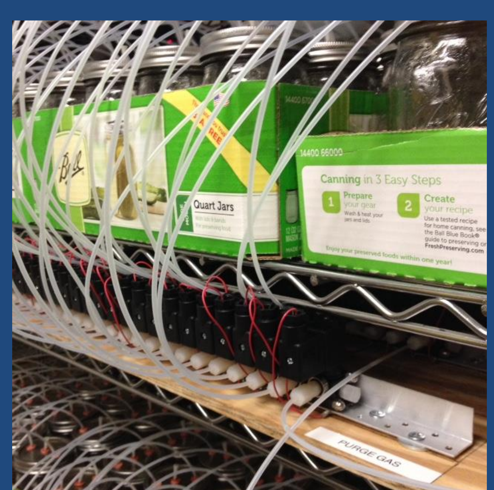
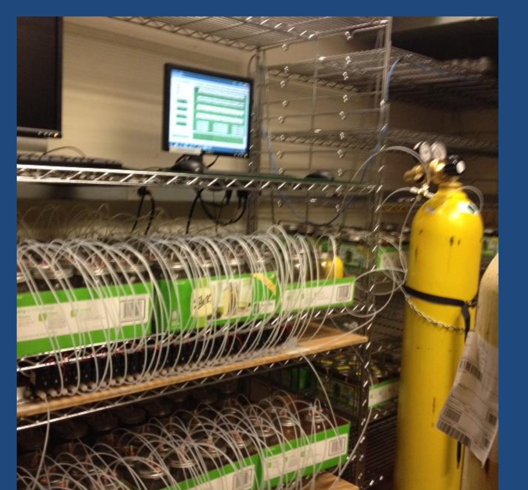


Figure 8: Data from our most recent incubation depicting negative priming with char additions and positive priming with the addition of an equivalent amount of uncharred biomass. Soil used for this experiment is an organic rich soil from Sweden.





Sample name	date analyzed	biomass type	δ13C	atom % 15N	amount (g)
W1	dec	willow	1534.6		na
R1	dec	rye	1596.05		na
W2S	jan	willow stems	896.12	8.08	25
W2L	jan	willow leaves	912.47	8.16	119
W3S	jan	willow stems	709.62	8.14	38
W3L	jan	willow leaves	722.63	8.36	128
W4S	jan	willow stems	824.51	7.41	352.2
W4L	jan	willow leaves	1109.11	8.13	468.2
roots	jan	rye roots	126.69	2.37	lots
R2	jan	ryegrass	1303.03	7.98	155
R3	jan	ryegrass	901.79	8.52	168
R4	jan	ryegrass	1081.6	7.9	143
R5	jan	ryegrass	992.01	8.77	202
R6	jan	ryegrass	686.94	8.15	123.6
R7	jan	ryegrass	376.55	8.88	209
R8	jan	ryegrass	683.04	8.39	211.3

Left: the majority of Silene's graduate career: growing labeled biomass and picarro stable isotope analyzer assembly. Table: C and N analyses for most of the biomass grown thus far. Highlighted in red are the values that will hopefully be high enough for nano-SIMS work.

References
Bird MI, Moyo C, Veenendaal EM, Lloyd J, Frost P. 1999. Stability of elemental carbon in a savannah soil. *Global Biogeochemical Cycles,* 13, 923-932; Singh N, Abiven S, Maestrini B, Bird J, Torn M, Schmidt M. 2013. Transformation and Stabilization of pyrogenic organic matter in a temperate forest field experiment. *Global Change Biology, 20, 1629-1642;* Lehmann J, Joseph S. 2009. *Biochar for Environmental managers.* Earthscan, London; Whitman T, Enders A, Lehmann J. 2014. Pyrogenic carbon additions to soil counteract positive priming of soil carbon mineralization by plants. *Soil Biology & Biochemistry. 73, 33-41;* Whitman T, Zhu Z, Lehmann J. 2014, Carbon Mineralizability Determines Interactive Effects on Mineralization of Pyrogenic Organic Matter and Soil Organic Carbon. *Environmental Science and Technology*. In Press; Dharmakeerthi R.S., Hanley K, Whitman T, Woolf D, Lehmann J. 2015. Organic carbon dynamics after additions of pyrogenic organic matter and crop residues over seven years. *Soil Biology and Biochemistry*. In review.